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## Development of Twin Rotary Compressor with New Heat Caulking Fixing Method

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### ABSTRACT

Conservation of energy and the saving of resources are executed in refrigeration cycle equipments aiming at the environmental protection. Especially, the effect of the improvement of the compressor, which is a key device of the refrigeration cycle equipment, is large, so development of new technology for making both higher efficiency and compact is pressing need. We have developed a Twin Rotary Compressor with a New Heat Caulking Fixing Method, which is the specific technology for fixing the mechanical component and shell, instead of Arc Spot Welding Method. This method greatly reduces the stress and strain that occurs to the mechanical component when fixing the shell. We expanded the stroke volume at the same outer diameter of the shell and improved compressor efficiency by thinning the mechanical component at the same stroke volume. This paper introduces the mechanism of the new fixing method and the effective of use gained by this method.

### 1. INTRODUCTION

For the motor of the compressor used for the room air conditioners, it has come to be used the brush-less DC motor (BLDCM) with rare earth permanent magnets take place of the ferrite magnets because of their higher magnetic induction and compact size. We have already developed high efficiency and compact compressors for 6-pole "Joint-lapped" BLDCM using rare earth permanent magnets with the same stroke volume<sup>[1]</sup>. Naturally, the application of a high power motor is not only for its compact size but also to increase the stroke volume with the same outer diameter shell. The latter development has advantages for refrigeration cycle equipments because it increases the cooling (and heating) capacity as well as saving resources by downsizing the case, however there were some restrictions in the compressor design. One of them was the arc spot welding method for fixing the mechanical component and shell. We have developed the Twin Rotary Compressor with a New Heat Caulking Fixing Method instead of arc spot welding method. This paper introduces the mechanism of the new fixing method and the effective of use gained by this method.

## 2. Restriction of increasing the stroke volume

### 2.1 Compressor efficiency and loss

Fig.1 shows the cross section of the twin rotary compressor installed in a room air conditioner with a capacity of 5.0kW class. The mechanical component and the motor are fixed to the shell. The compressor is a high-presser shell type that compresses the refrigerant gas sucked through the suction muffler in the mechanical component, and then is discharged in the shell. Fig.2 shows the compression process of the rotary compressor. The rolling piston rotates eccentricity in the cylinder and the vane reciprocates in the vane slot of the cylinder. These divide into the suction and the compression chamber. There has to be adequate clearance between each sliding part to maintain the effectiveness of the lubricant.

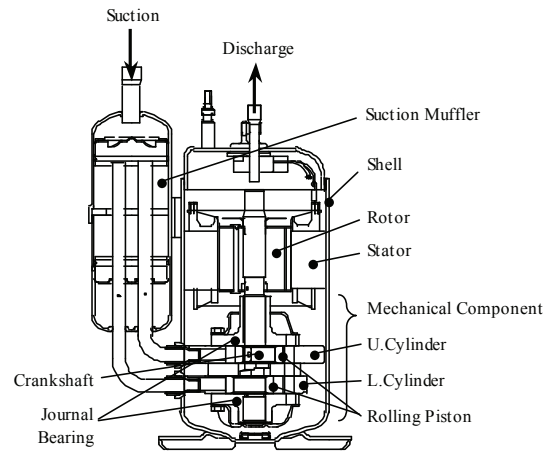


Fig.1 Cross Section View

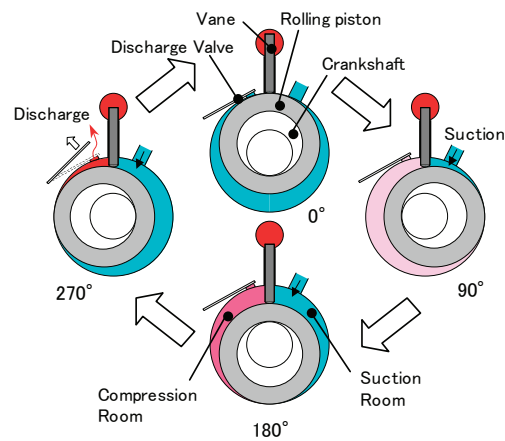


Fig.2 Compression Process

Table.1 shows the classification of loss factors. The compressor efficiency is divided into the motor efficiency, the mechanical efficiency, and the indicated efficiency<sup>[2]</sup>.

$$\text{Motor efficiency} \quad \eta_m = L_m / L_c \quad (1)$$

$$\text{Mechanical efficiency} \quad \eta_{me} = L_i / L_m \quad (2)$$

$$\text{Indicated efficiency} \quad \eta_c = L_{ad} / L_i \quad (3)$$

$$\text{Compressor efficiency} \quad \eta_{comp} = \eta_m \cdot \eta_{me} \cdot \eta_c \quad (4)$$

Where  $L_m$  is motor output,  $L_i$  is indicated work,  $L_c$  is consumption power,  $L_{ad}$  is adiabatic work shown as follows.

$$\text{Adiabatic work} \quad L_{ad} = \eta_v Gr_{th} \Delta h_{comp} \quad (5)$$

$$\text{Volumetric efficiency} \quad \eta_v = Gr / Gr_{th} \quad (6)$$

Where  $Gr_{th}$  is theoretical refrigerant flow,  $\Delta h_{comp}$  is theoretical increment of enthalpy,  $Gr$  is real refrigerant flow.

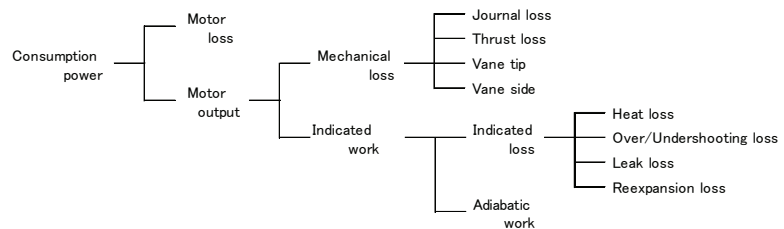
Among the compressor losses in Table.1, the leakage loss is divided into the vane side, vane top, rolling piston side, rolling piston top as shown in Fig.3. The leakage loss is shown as follows assuming that the leakage flow is one-dimensional flow of a compressible fluid.

$$w = \varphi \cdot A \cdot \sqrt{\frac{2\kappa}{\kappa-1} \cdot P_2 \cdot \rho_2 \cdot \left( F^{\frac{2}{\kappa}} - F^{\frac{\kappa+1}{\kappa}} \right)} \quad (7)$$

$$\text{when } P_1 / P_2 \geq F_c \quad F = P_1 / P_2$$

$$P_1 / P_2 \leq F_c \quad F = F_c = (2 / (\kappa + 1))^{\frac{\kappa}{\kappa-1}}$$

Table.1 Classification of Loss Factor Compression Process



Where  $w$  is mass flow ratio of leakage,  $\phi$  is coefficient of flow,  $A$  is cross sectional area of clearance which is geometrically determined at each crank angle,  $\kappa$  is adiabatic exponent,  $P_1$  is lower pressure,  $P_2$  is higher pressure,  $\rho_2$  is density,  $F_c$  is critical compression ratio. Mass flow ratio of leakage is proportional to the cross sectional area of clearance, pressure condition, density, and coefficient of flow.

The mechanical loss is shown by the fluctuating load in each sliding part, the sliding speed and the coefficient of friction. In the rotary compressor the vane side loss is proportional at the load by the refrigerant gas pressure, the vane reciprocating distance, and the rotational speed of the crankshaft. The vane tip loss is proportional at the load by refrigerant gas pressure and the rolling piston rotational speed. The journal loss is proportional to the load by refrigerant gas pressure act on the bearing and rotational speed of the crankshaft. The thrust loss is proportional to weight of the crankshaft and rotor, axial component of motor torque, and rotational speed of the crankshaft.

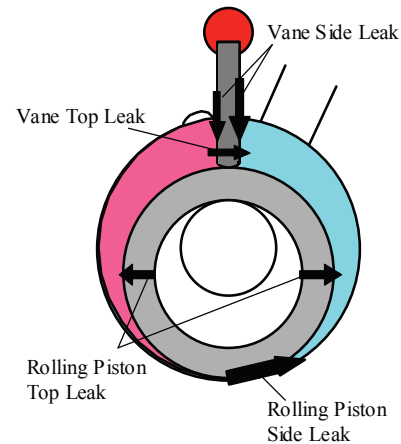


Fig.3 Leakage Path of Compression chamber

## 2.2 Expansion of the stroke volume

The stroke volume of the rotary compressor is shown as follows.

$$V_{st} = \frac{\pi}{4} (D^2 - d^2) h \quad (8)$$

$$d = D - e \quad (9)$$

Where  $V_{st}$  is stroke volume,  $D$  is inner diameter of the cylinder,  $d$  is outer diameter of the rolling piston,  $h$  is height of the cylinder. Two is multiplied for the twin rotary compressor.

There are three methods of expanding the stroke volume, expansion of the inner diameter of the cylinder, reduction of the outer diameter of the rolling piston and increasing of the height of the cylinder. As shown in Fig.3, reduction of  $d$  causes a lack of the seal length. Increasing of the  $h$  causes expansion of the flow passage area of the rolling piston side leakage and the vane side leakage (an increase of the  $A$  in equation (7)). The expansion of  $D$  is an ideal technique because it does not increase the leakage loss. However, there was an issue, which is explained as follows.

## 2.2 Issues with expanding the inner diameter of the cylinder

For fixing the mechanical component and the shell, it is necessary to fit both these concentric and keep it while fixing. Arc spot welding method that satisfies such demands is widely used. However, the arc spot welding method does not avoid the reaction force in the radial direction because the welding material intrudes upon the area between the cylinder and the shell (Fig.4). The reaction force causes strain to the vane slot and the inside diameter of the cylinder. If the rigidity of the cylinder is reduced, then it becomes necessary to widen the clearance of each sliding part of the mechanical component to keep the reliability of the lubricant. It causes an increase in the leakage path and decreases the efficiency of the compressor. The expansion of the inner diameter of the cylinder is difficult to determine to secure adequate rigidity of the cylinder when using the arc spot welding method.

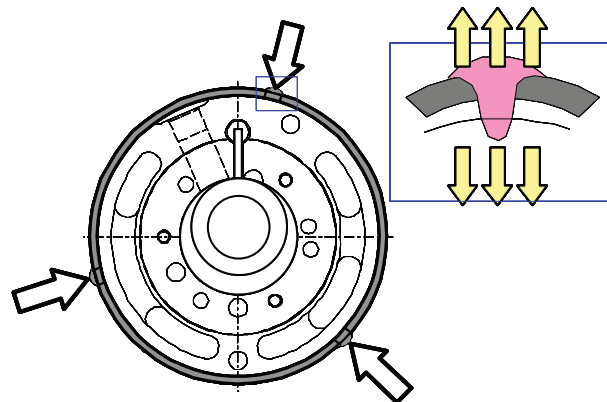


Fig.4 Reaction Force of the Arc Spot Welding Method

### 3. New Heat Caulking Fixing Method

#### 3.1 Mechanism of the Heat Caulking Fixing Method

We have developed a New Heat Caulking Fixing Method that enables the strain of the mechanical component to be decreased from the arc spot welding method. We describe the mechanism with Fig.3.

- 1) Three pairs of prescribed hollows are processed to a fixing part of the cylinder (Fig.5 shows only one part)
- 2) The shell is heated to a degree higher than the softening point by a high frequency heater, and is pushed with a prescribed tool
- 3) The softened shell is molded in the projection by filled to the hollows of the cylinder
- 4) The three pairs of projections hold the cylinder by shrinkage force when the shell is cooled

#### 3.2 Decreasing the strain

When pushing the shell, the new fixing method decreases the impact load by heating the shell to over the softening point compared with cold working. The fixing force holds the cylinder is predominantly the circumferential force not radial force in the arc spot welding method. This new fixing method decreases the strain of the vane slot and also to the inside of the cylinder. Fig.6 is strain data comparison of the new and previous fixing method of the vane slot with same rigidity of the cylinder. It is confirmed that the strain is decreased by half.

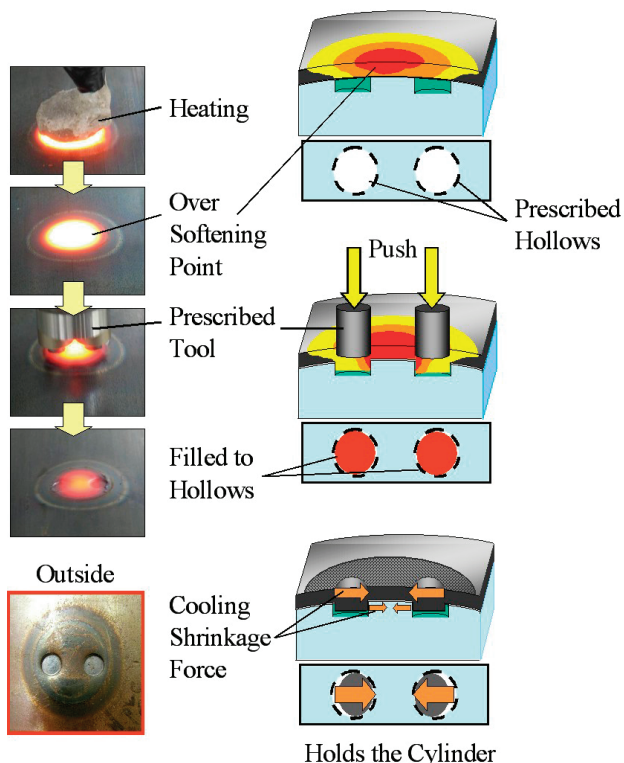


Fig.5 Heat Caulking Fixing Method

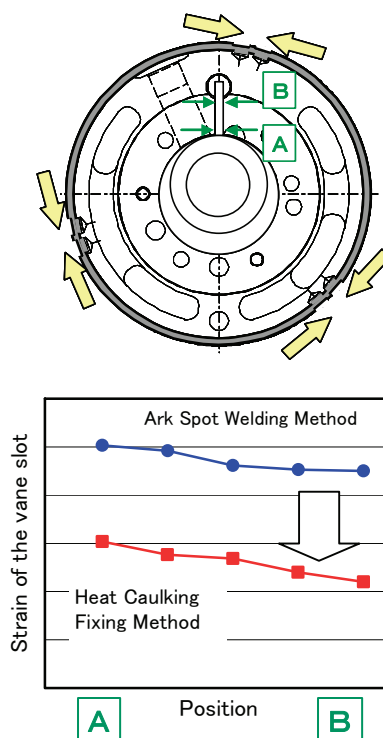


Fig.6 Heat Caulking Fixing Method

## 4. Application of the New Heat Caulking Fixing Method for Twin Rotary Compressor

### 4.1 Expansion of the stroke volume

Because the New Heat Caulking Fixing Method decreases the radial reaction force, an increase of the strain can be controlled to a structural change to decrease the rigidity of the cylinder. The inner diameter of the cylinder is expanded without the need to expand the outer diameter of the shell. This expands the stroke volume to 17.2cc from 13cc which was the upper limit. This equaled a model series that the outer diameter of the shell is one size larger, and achieved great downsizing and making to highly efficiency (Table.2).

Table.2 Comparison data of new and previous model

	New	Previous	
Stroke Volume	17.2cc	17.5cc	13.0cc
Shell O.D.	$\phi$ 112.2	$\phi$ 129.6	$\phi$ 112.2
Weight	8.4kg	13.8kg	8.4kg
Ratio of COP <sup>1</sup>	107%	Base	–

<sup>1</sup>CT/ET=54.4/7.2(C), SC/SH=8.3/27.8(C), 60rps

### 4.2 Improvement of the compressor efficiency

In addition, we achieved in making it highly efficient at the same stroke volume because of the expansion of the inner diameter of the cylinder by using of the new fixing method. The inner diameter of the cylinder  $D$  is expanded 10% and the height of the cylinder  $h$  is reduced 24% at the same stroke volume. Fig.7 compares the ratio of leakage losses between the new and previous model in the measurement base. By reducing of  $h$ , the flow passage area of the rolling piston side leakage and the vane side leakage are reduced so these leakage losses are improved. Although the vane top loss is deteriorated because of  $e$  increase by  $D$  expansion, the total leakage loss ratio is improved more over 10%. In the mechanical loss, by reduction of  $h$ , the receiving pressure area and the load of the journal bearing is decreased and the journal loss is improved. Although the vane side loss is deteriorated because of reciprocating distance increase by  $e$  increase, these losses are almost same. Making 3.4% highly efficiency was achieved by improvement of the leakage loss by the above-mentioned dimension changes and improvement of the reexpansion loss, overshooting loss, and motor loss.

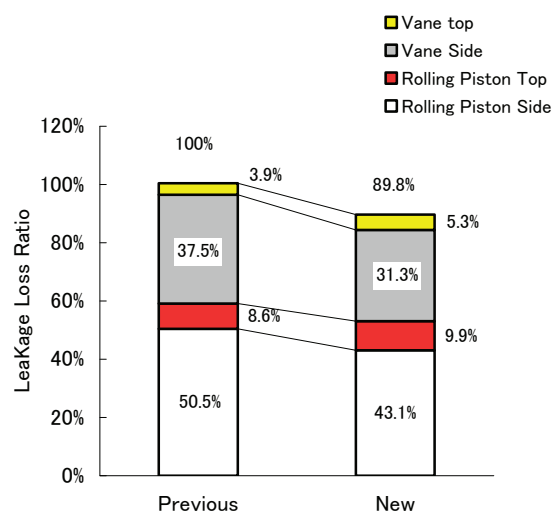


Fig.7 Comparison of Leak Loss Ratio  
CT/ET=54.4/7.2(C), SC/SH=8.3/27.8(C), 60rps

## **5. Conclusions**

- 1) We showed that the New Heat Caulking Fixing Method is able to reduce the strain in the cylinder to the half by the reduction of the radial reaction force compared to the Arc Spot Welding Method.
- 2) The stroke volume was expanded to 17.2cc from 13cc with the outer diameter of the shell at 112.2mm by applying the new fixing method.
- 3) The leakage loss was improved more over 10% by reduction of the cylinder height at the same stroke volume by applying the new fixing method. Making 3.4% highly efficiency was achieved by improvement of the leakage loss and other losses.

## **6. References**

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